SIMPLE DAMAGE MODEL FOR CRACKED THIN PLATE TENSILE TEST

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A report submitted in partial fulfilment of the requirements
For the award of the degree of
Of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

ABSTRACT

Simple damage model was a preliminary study in order to identify the need of assessment of method for cracked thin plate because the important for safe operation and maintenance especially in oil and gas industry. This study was dividing into 2 step which is experimental and FEA analysis using MSC PATRAN Software. For this project, the Finite Element Analysis result will compare to the experiment and the parameter will be added to see the change in the coalescence load versus crack size diagram between experiment and simulation. For the experiment, the project scope was focus on the API Grade B Specimen that has been machining into ASTM E8 standard size of tensile test specimen. Crack size for the specimen has been varying into 3 different sizes which are 4mm, 6mm, and 8mm crack size in order to examine the maximum tensile stress, strain and load for different crack size of the specimen. Afterward, using MSC Marc Patran Simulation the parameter will be added to generate simple damage model equation accurately and the results of finite element analysis can simplify working process and reduce working time to do an experiment. In the analysis, the parameters used are 2mm, 4mm, 6mm and 8mm crack size and also included in the analysis the material yield strength and poisson ratio. Based on the experimental and analysis, stress versus strain graph obtained and the result of the maximum stress, strain and load for the uncrack specimen and other parameter are compared. Besides that, simple damage model equation was obtained from load versus crack size diagram in order to predict the maximum load from various size of crack by using crack as the x parameter and y as the value of maximum load from finite element analysis result. These finding led to the conclusion that the maximum load are proportional to the crack size which is bigger the crack size of the specimen, the maximum load are decreased.

ABSTRAK

Model kerosakan mudah untuk plat nipis yang mempunyai retakan dan ujian tegangan adalah satu kajian awal untuk menentukan perlunya untuk membuat penaksiran tentang kaedah untuk plat nipis yang mempunyai retakan kerana ia penting di dalam operasi yang selamat dan penyelenggaraan terutama di dalam industri minyak dan gas. Kajian ini telah dibahagikan kepada 2 bahagian iaitu eksperimen dan FEA analisis dengan menggunakan perisian MSC PATRAN. Untuk projek ini, FEA analisis akan dibandingkan dengan hasil kajian daripada eksperimen yang telah dilakukan dan parameter akan ditambahkan untuk melihat perubahan tautan antara beban melawan saiz retakan diantara eksperimen dan simulasi. Pertamanya, untuk eksperimen skop untuk projek ini adalah fokus kepada penggunaan bahan daripada API Gred B yang telah diproses menggunakan mesin kepada saiz yang telah ditetapkan di dalam piawaian ASTM E8 untuk sampel ujian tegangan. Saiz retakan untuk sampel – sampel yang diperlukan telah dibezakan kepada 3 saiz retakan yang berlainan iaitu 4mm, 6mm dan 8mm dalam usaha untuk mengkaji tekanan tegangan dan bebanan maksimum untuk saiz retakan yang berlainan. Selepas itu, dengan menggunakan simulasi MSC Marc Patran, parameter akan ditambah untuk menghasilkan persamaan model retakan mudah yang lebih tepat dan hasil kajian daripada simulasi ini juga dapat mengurangkan proses kerja dan mengurangkan masa kerja untuk melakukan eksperimen. Daripada analisis, parameter yang digunakan adalah 2mm, 4mm, 6mm dan 8mm saiz retakan dan di dalam simulasi ini juga disertakan ‘yield strength’ dan ‘poisson ratio’ untuk bahan yang digunakan. Berdasarkan eksperimen dan analisis, graf Stress melawan strain diperoleh dan semua data yang diperoleh akan dibandingkan antara simulasi dan juga eksperimen untuk setiap parameter. Selain itu, persamaan model kerosakan mudah telah diperolehi daripada beban melawan saiz retakan untuk meramalkan beban maksimum dari pelbagai saiz retakan dengan menggunakan retakan sebagai parameter x dan nilai beban maksimum sebagai y daripada hasil FEA analisis. Penemuan ini membawa kepada kesimpulan bahawa beban maksimum adalah berkadar terus dengan saiz retakan dimana yang semakin besar saiz retakan sesuatu sampel, beban maksimum semakin menurun.

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LIST OF SYMBOLS

σ	Stress
ϵ	Strain
σe	Engineering Stress
$\sigma \tau$	True Stress
$\epsilon \tau$	True Strain
ϵe	Engineering Strain
ln	Natural Log
C	Carbon
Mn	Manganic
P	Phosphorus
S	Sulphur
Si	Silicon

LIST OF ABBREVIATIONS

API	American Petroleum Institute
MSC	MacNeal-Schwendler Corporation
HAZ	Aluminium
ASTM	American Society for Testing and Materials
FEA	Finite element analysis
EDM	Electro – discharge machining
CMD	Command Prompt

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter will explain briefly about the synopsis of this study and some background of the study about simple damage model for cracked thin plate tensile test. This chapter consist background of the study, objective, scopes and also problem statement.

1.2 BACKGROUND OF THE STUDY

It is impossible to keep petroleum and natural gas transmission pipelines free from defects in the manufacturing, installation and servicing processes. The damage might endanger the safety of pipelines and even shorten their service life. Gas or petroleum release due to defects may jeopardise the surrounding ecological environments with associated economic and life costs. Also, steel structures such as pipelines for offshore and onshore industry are prone to suffer various types of damage as they get older. Under the action of repeated loading, fatigue cracks may be initiated in the stress concentration areas of the piping. The threshold for crack initiation increases with the pre-deformation due to a strain hardening effect, while the fatigue resistant factor exhibits a maximum with pre-deformation owing to its special dependence on fracture strain and fracture strength. The result is expected to be beneficial to the understanding of the effect of damage on the safety of pipelines and fatigue life prediction. (Jiang, Y.& Chen, M., 2012)

1.3 PROBLEM STATEMENT

There are several methods to predict failure on the steel structures for cracked structure especially pipelines but sometimes accident happens and it might endanger life and harm certain parties. The need of assessment of method for cracked thin plate is important because of the structural engineering is increasing important for safe operation and maintenance especially in oil and gas industry. Even the best designed and maintained pipeline will become defective as it progresses through its design life. Therefore, operators need to be aware of the effect these defects will have on their pipeline, and more importantly be able to assess their significance in terms of the continuing integrity of the pipeline.Despite the convenience provided by simulation software, however there are still errors that arise due to material properties, technical issues and less proper procedures while performing the analysis. Besides that, the tensile tests on cracked thin plate are important in order to assume the lifespan of the pipelines.

1.4 OBJECTIVE

The objectives of this study are:

i) To determine the stress strain curve for cracked thin plate.
ii) To develop a load versus crack size diagram using a various crack size and generate simple damage model equation for cracked thin plate tensile test.

1.5 SCOPES

This project will focus on the following points:

i) Material used is API Steel 5L Grade B.
ii) Tensile test for cracked tensile specimen to obtain the stress strain curve
iii) To simulate the crack by using Software MSC Marc 2008 r1 and compare the experiment test and simulation.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will explained briefly about the pipeline and relation to the important of tensile test on cracked thin plate. It includes material used in pipeline, defects on pipelines, ultimate tensile strength of steel plates with cracking damage, method to predict failure behaviour and also about tensile test. Literature review is important to know the previous study that related to this project

2.2 INTRODUCTION TO PIPELINES

Pipeline is important in transportation natural gas and other products in oil and gas industry either in offshore or onshore. The most defect occur are corrosion but fatigue cracking is another important factor of age related structural degradation, which has been a primary source of costly repair work of aging steel structures. Cracking damage has been found in welded joints and local areas of stress concentrations such as at the weld intersections of longitudinal, frames and girders. Fatigue cracking has usually been dealt with as a matter under cyclic loading, but it is also important for residual strength assessment under monotonic extreme loading, because fatigue cracking reduces the ultimate strength significantly under certain circumstances.(Paik, J. K., *et al.*, 2004). There are few factors that will affect pipeline failure performance such as good design, materials and operating practices. In this chapter, there are type of defect that usually occurs, material selection of common pipelines and also the method to predict failure behaviour.

Figure 2.1below shows a schematic representation of the nonlinear behaviour of cracked steel structures under monotonic loading. It is noted that for similar structures the stiffness and ultimate strength of cracked structures is smaller than those of uncracked structures.(Paik, J. K., *et al.*, 2004).

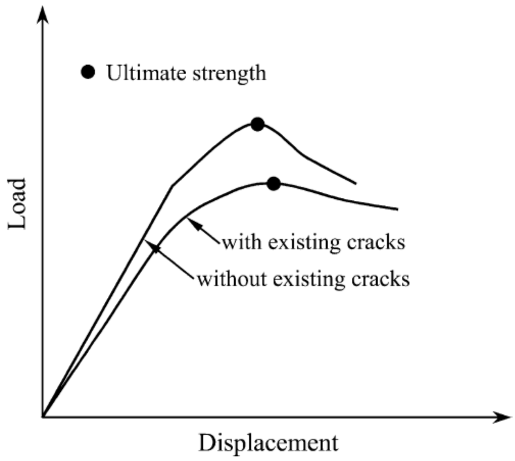

Figure 2.1: A schematic representation of the cracking damage effect on the ultimate strength behaviour of steel structures.

Source: Paik, J. K., *et al.*, 2004

2.3 MATERIAL USED IN PIPELINE

Materials used in pipelines are varying be influenced by on the type of element that will be transporting by the pipeline. Today, the X70 pipeline steel is widely used in the world, the X80 pipeline steel began to apply in some developed countries and the research and development of X100/X120 pipeline steel is being studied in the recent years. In our country, the X60 pipeline steel is widely used in the working pipelines. The X70 pipeline steel is used in the West-East Gas Pipeline Project. Most of the researches are focus on the fatigue failure of the pipeline steel, especially the fatigue crack propagation of the pipeline steels. (Jiang, Y.& Chen, M. 2012).

The researches and industrialization of pipeline steel fatigue crack propagation are summarized, especially the X60 and X70 pipeline steel after the mechanical damage and in the synthetic soil solution. (Jiang, Y.& Chen, M. 2012).Line pipe grade designations come from API Spec 5L Specification for Line Pipe. For standard pipeline, the grade are A and B but the stronger grades have the designation of X. For example, X42 until X80. Table 2.1 shows the physical properties of the line pipe.

Table 2.1: Physical properties of the line pipe

API 5L Grade	Yield Strength min. (MPa)	Tensile Strength min.(MPa)	Yield to Tensile Ratio (max.)	Elongation min.%
A	207	331	0.93	28
B	241	414	0.93	23
X42	290	414	0.93	23
X46	317	434	0.93	22
X52	358	455	0.93	21
X56	386	490	0.93	19
X60	414	517	0.93	19
X65	448	530	0.93	18
X70	482	565	0.93	17
X80	551	620 ~ 827	0.93	16

Source: www.woodcousa.com, Internet Sources

API 5L elongation figures vary with specimen dimensions. As for the elongation taken in table above, the value are for 130 mm^2.

2.4 DEFECTS IN PIPELINE

Oil and gas transmission pipelines basically have a good safety records. This is due to a combination of decent design, materials and operating observes; however, like any engineering structure, pipelines at times will fail. The most common causes of damage and failures in onshore and offshore transmission pipelines are mechanical damage which is cracks and corrosion. (Jiang, Y.& Chen, M. 2012).

2.4.1 Corrosion

Corrosion is an electrochemical process it usual appears as either general corrosion or localised corrosion. Figure 2.2 below shows the irregular length, width and depth of a typical corrosion defect. There are many different types of corrosion, including galvanic corrosion, microbiologically induced corrosion, AC corrosion, differential soils, differential aeration and cracking. It can occur on the internal or external surfaces of the pipe, in the base material, the seam weld, the girth weld, and/or the associated heat affected zone (HAZ). (Cosham, A.& Hopkins, P. 2003).

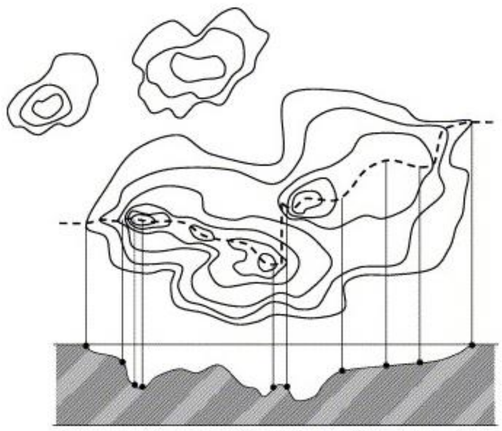

Figure 2.2: The irregular length, width and depth of a typical corrosion defect

Source: Cosham, A., & Hopkins, P. 2003

2.4.2 Dents

A dent in a pipeline is a permanent plastic deformation of the circular cross section of the pipe. A dent is a gross distortion of the pipe cross-section and Figure 2.3 show the dimension of the dent. Dent depth is defined as the maximum reduction in the diameter of the pipe compared to the original diameter. This definition of dent depth includes both the local indentation and any divergence from the nominal circular cross-section. (Cosham, A., & Hopkins, P. 2003).

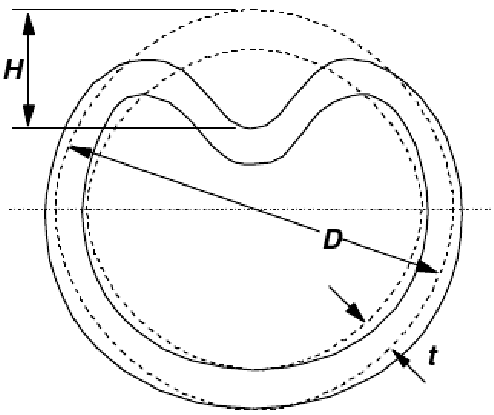

Figure 2.3: Dimension of the dents

Source: Cosham, A., & Hopkins, P. 2003

According to Cosham, A.& Hopkins, P. 2003, there are few different type of dent exists. For example, smooth dent which is a dent which causes a smooth changes in the curvature of the pipe wall in a pipelines. Besides that, kinked dent which is a dent which causes an abrupt change in the curvature of the pipe wall (radius of curvature (in any direction) of the sharpest part of the dent is less than five times the wall thickness). Another type is smooth dent that contains no wall thickness reductions (such as a gouge or a crack) or other defects or imperfections (such as a girth or seam weld), unconstrained dent which is dent free to rebound elastically (spring back) when the indenter is removed, and is free to reround as the internal pressure changes.

2.5 CAUSES OF PIPELINE FAILURE

Failure of an operating gas pipelines is a rare event. It is extremely serious event but it statistics shows that failures only occur once in a year per thousand miles of pipelines. Yet, when failure occur prevention must be apply because of the potential of losing life. It must be well analysed to prevent relapse. Figure 2.4 shows the number of gas pipelines services incident versus year of occurrence by cause.(Giedon, D.N and Smith R.B. 1980.)

Based on the Figure 2.4, over half of the operating pipelines failures are resulting from some externally applied mechanical force and also shows failure that occurs by cause which is outside force, material failure and corrosion.

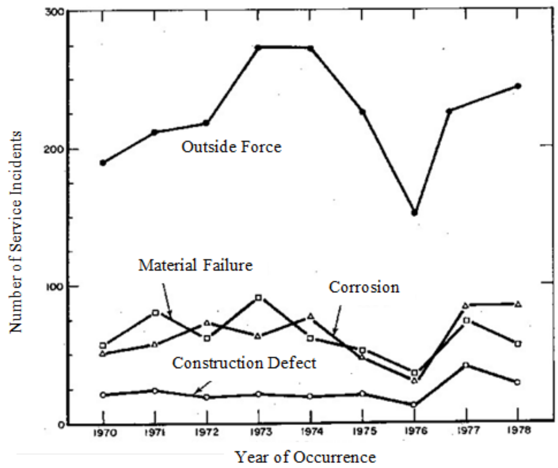

Figure 2.4: Number of gas pipeline service incidents versus year of occurrence by cause.

Source: Giedon, D.N and Smith R.B., 1980

2.5.1 Outside Force

External interference, mostly third party activity involving interference using machinery, has been recognised as a dominant failure mechanism both in gas and oil-industry pipelines. Precise records of the location and the depth of a pipeline should always be kept and communicated to any contractors before commissioning of planned work in the area. All other types of incidents appear to have some kind of connection with the activities and safety measures taken or not taken by the operator. (Papadakis, G. A. 1999)

2.5.2 Material Failure

As for material defect, it is not common causes of service failures because they are usually found before the pipe is placed in service, either during inspection of the pipe or during hydrostatic testing. (Giedon, D.N and Smith R.B., 1980)Construction and material defects (caused during processing or fabrication) are often connected with equipment associated with the pipeline. (Papadakis, G. A. 1999)

2.5.3 Corrosion

Corrosion is another major causative factor for incidents and mostly attacks pipelines as they are ageing. It can cause failures by thinning the wall over a large area or localized pitting. There also another form of corrosion which is stress-corrosion cracking that also can lead into failures. This failure is results from the accumulation of moisture on the pipe surface at imperfections in the pipe coating. Stress corrosion cracking in pipelines is identified by the distinctive intergranular nature of the crack. (Giedon, D.N and Smith R.B., 1980)

2.6 STRESS - STRAIN CURVE

One of the most common mechanical stress–strain tests is performed in tension. The tension test can be used to ascertain several mechanical properties of materials that are important in design. A specimen is deformed, usually to fracture, with a gradually increasing tensile load that is applied uniaxial along the long axis of a specimen. The tensile testing machine is designed to elongate the specimen at a constant rate and to continuously and measure the instantaneous applied load and the resulting elongations. (William D. Callister. 2006).

Typical stress- strain curve normally have four deformation changes as shown in Figure 2.5 below. It started from point a, which the elastic deformation starting to occur and it occur only to strain of about 0.005. As the material is deformed beyond this point, the stress is no longer proportional to strain and after that plastic deformation occurs. Point b the yield strength occur, that the point where the transition between elastic – plastic on the deformation. The point of yielding may be determined as the initial departure from linearity of the stress–strain curve. After yielding, the stress necessary to continue plastic deformation increases to a maximum strength at point c and then decreases to the eventual fracture, point d. The tensile strength is the stress at the maximum on the engineering stress–strain curve. This corresponds to the maximum stress that can be sustained by a structure in tension and if this stress is applied and maintained, fracture will result.(William D. Callister. 2006)

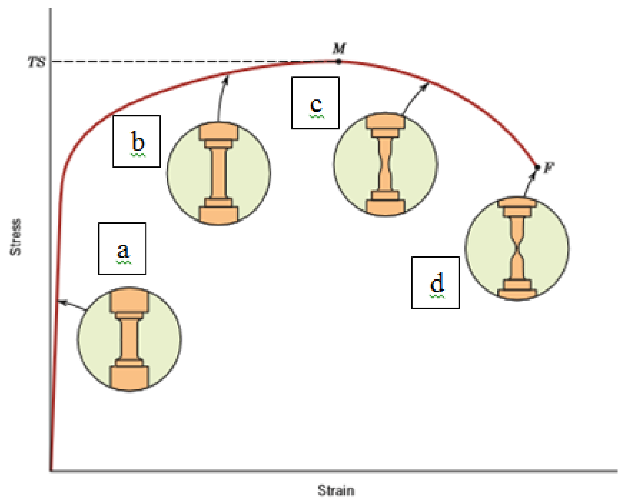

Figure 2.5: Typical engineering stress– strain behaviour to fracture

Source: William D. Callister, 2006

2.6.1 True Stress – Strain Curve Compare to Engineering Stress – Strain Curve

The engineering stress is the load taken by the sample divided by the original area. Meanwhile the true stress is the load that gets by the sample divided by a variable the instantaneous area as shown in the Figure 2.6 below. The figure shows the comparison of engineering and true stress-strain curves. Note that the true stress always rises in the plastic, whereas the engineering stress rises and then falls after going through a maximum.

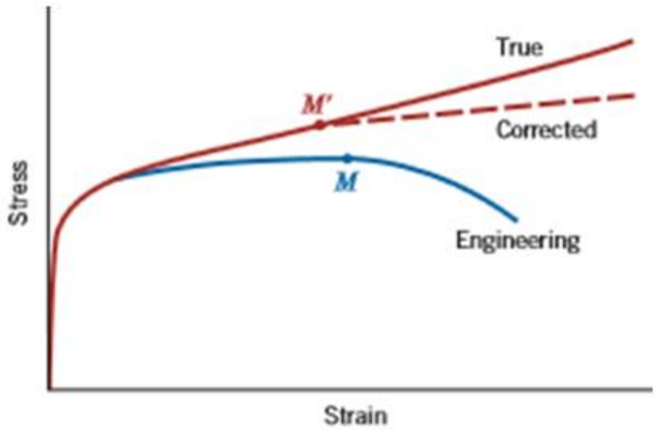

Figure 2.6: A comparison of typical tensile engineering stress–strain and true stress–strain behaviours

Source: William D. Callister, 2006

Necking begins at point M on the engineering curve, which corresponds to on the true curve. The "corrected" true stress– strain curve takes into account the complex stress state within the neck region. Engineering stress and strain can be computed from the experiment which is the engineering stress, σe get from the load measured in the tensile test divide to the original area. Meanwhile, the engineering strain, ϵe can be get from deformation divide with original length as shown in equation (2.1) and (2.2). (Ling, 1996).

$$\sigma e = \frac{P}{AO} \tag{2.1}$$

$$\epsilon e = \frac{\Delta l}{lO} \tag{2.2}$$

$$\sigma\tau = \sigma(1+\epsilon) \tag{2.3}$$

$$\epsilon\tau = ln\ (1+\epsilon) \tag{2.4}$$

Equations (2.3) and (2.4) are the true stress and strain that can be computed from actual load, cross-sectional area, and gauge length measurements.